

HIGH ENERGY PHYSICS

Anti-proton Production

from a Correspondent

THE possibility of matter and antimatter co-existing inside a galaxy is suggested in some cosmological models such as that of Alfrén (*Rev. mod. Phys.*, **37**, 652; 1965). The presence of a source region of antimatter somewhere in the Galaxy would be implied if an appreciable quantity of antimatter was to be detected in the primary cosmic ray flux. Experiments reported to date have only been able to yield upper limits to the proportion of antiparticles ($\lesssim 0.1\%$). Indeed no one seems to have positively identified even one antinucleon reaching the vicinity of the Earth.

Although 90% of cosmic ray particles are known to be protons many experiments concentrate on looking for antihelium and heavier antinuclei rather than antiprotons. This is to avoid the problem of having to correct for the secondary flux of antiprotons produced in the collisions of primary cosmic rays with interstellar gas. Experiments (for example looking for antihelium using superconducting magnetic spectrometers flown in balloons) therefore generally suffer from lack of a significant number of events (see, for example, Buffington *et al.*, *Nature*, **236**, 335; 1972).

A considerable improvement in statistics could be achieved by measuring the antiproton to proton ratio, provided the contamination due to secondary effects can be accurately calculated. Previous attempts at such calculations have suffered from the lack of sufficient information on the antiproton (\bar{p}) production cross-section ($p + \bar{p} \rightarrow p + \text{anything}$). Recently, however, T. K. Gaisser and R. H. Maurer (*Phys. Rev. Lett.*, **30**, 1264; 1973) have used data now available on \bar{p} production from the CERN intersecting storage rings (ISR) to calculate the expected \bar{p}/p ratio due to collision effects. Their results place a conservative upper limit of $\bar{p}/p \lesssim 4.6 \times 10^{-4}$ arising from interstellar gas collisions at all energies.

Drs Gaisser and Maurer have derived an expression for \bar{p} production based on both conventional accelerator data and that from ISR. Interpolation between these sets of data and extrapolation beyond ISR energies (> 53 GeV in the centre of mass frame) are carried out on the basis of the scaling hypothesis of Feynmann.

The \bar{p} production inclusive cross-section is then used to calculate the expected \bar{p}/p ratio. Because the mean path length of matter traversed by primary protons between their source and observation at Earth ($\sim 3\text{--}5$ g cm $^{-2}$) is much less than the interaction length for protons in hydrogen, the authors assume that each proton interacts at the

most with one hydrogen nucleus, and also neglect further interactions of the produced antiprotons. With the further assumptions that the primary cosmic ray flux in interstellar space is primarily protons with the same energy spectrum as observed in the vicinity of the Earth and that \bar{n} production equals \bar{p} production, an expression for the differential spectrum for antiprotons is derived. Feeding in a power law primary cosmic ray energy spectrum ($dN \propto KE^{-2.6} dE$) yields the expected \bar{p}/p as a function of antiproton energy.

Their calculations yield a \bar{p}/p ratio initially increasing with energy but approaching an asymptotic limiting value of $\sim 4.6 \times 10^{-4}$ above ~ 100 GeV. Drs Gaisser and Maurer emphasize that the result is very much a firm upper limit to the \bar{p}/p ratio at all energies. They argue that the final asymptotic figure is either insensitive to the approximations used or can only be reduced by more accurate treatment.

The authors' conclusions do, however, seem to depend on the correctness of the scaling hypothesis. Most recent ISR work and data from cosmic ray workers have raised considerable doubts concerning the applicability of scaling. Thus there is an obvious need now to improve the experimental results to below the current upper limit of $\sim 10^{-3}$ for the \bar{p}/p ratio. Sorting out such a small proportion of antiprotons from protons, however, is a formidable task.

LOW TEMPERATURE PHYSICS

Another Sound

from our Condensed Matter Correspondent

A COMPLETELY new type of sound wave may exist in liquid helium-four above its superfluid transition temperature, T_λ , according to a calculation by D. C. Mattis and L. F. Landovitz of Yeshiva University, New York (*Phys. Rev. Lett.*, **30**, 1196; 1973).

The properties of liquid helium at temperatures above and below T_λ are so completely different that the two phases are distinguished by referring to them as He I and He II respectively. Most of the research effort has been directed towards reaching an understanding of He II whose superfluidity and other "anomalous" properties have made it a substance of intense fascination for both theoretical and experimental physicists. In comparison, He I has hitherto been regarded as relatively uninteresting, because its behaviour has seemed very similar to that of a dense classical gas.

It has long been known that in He II there are two entirely different modes of wave propagation, referred to as first and second sound, and travelling with very different velocities. First

sound is characterized by density fluctuations as in "ordinary" sound and by the superfluid and normal component of the liquid moving in phase with each other, whereas in second sound the two components move in antiphase, so that the net density remains constant. Because the proportion of superfluid falls to zero at T_λ , it has always been tacitly assumed that the only form of wave propagation in He II must be ordinary sound. Experiments have shown that, as expected, the velocity of sound in He I is not greatly different from that of first sound in He II, and that it can be measured continuously through the transition; but that the velocity of second sound falls rapidly to zero as the temperature rises to T_λ .

Mattis and Landovitz have now carried out a theoretical investigation of He I by considering collective excitations of the system, that is those involving the correlated motion of large numbers of atoms. Their calculation shows that, at temperatures above T_λ , there should be, in addition to ordinary sound, another much more slowly propagating wave.

For temperatures close to T_λ this wave should have the novel (for He I) character of being transverse, that is, the atomic motion being at right angles to the direction of propagation. With increasing temperature, however, the velocity of the wave rises and the character of the disturbance gradually becomes less well defined until, eventually, at a critical temperature T_b , the wave becomes indistinguishable from ordinary (longitudinal) sound. For temperatures above T_b the equations do not yield a wave solution. The authors suggest that T_b probably corresponds to the boiling point. In support of this thesis they report that the heat capacity, calculated on the basis of the same model, displays a "bump" at T_b ; and they believe that, if account could be taken of the weakly attractive interatomic forces, a latent heat would then be found, characteristic of the phase change from liquid to vapour.

Another interesting feature of their calculation is that, as the temperature falls, the velocity of the new wave drops to zero at T_λ . The fact that, in He II, the velocity of second sound also falls to zero but as the temperature rises to T_λ suggests that, in some sense, the new sound wave represents a continuation of the second sound mode of the He II, into He I.

The theoretical approach suggested by these authors may, perhaps, have laid the foundations for a new unified theory of both He I and He II. The most encouraging demonstration of the general validity of their ideas would be an experimental observation of the new wave-mode which they have predicted in this paper.